ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering

Tome XII [2014] – Fascicule 4 [November]
ISSN: 1584-2673 [CD-Rom, online]

a free-access multidisciplinary publication
of the Faculty of Engineering Hunedoara

[1.] H. D. OLUSEGUN, [2.] A.S. ADEKUNLE, [3.] S. OGUNDELE, [4.] I.O. OHIJEAGBON

# ANALYSIS OF LATERITE-GRANITE CONCRETE TILES COMPOSITE

[1.] Mechanical Engineering Department, Federal University of Technology, Minna, NIGERIA
[2, 4.] Mechanical Engineering Department, University of Ilorin, P.M.B. 1515, Ilorin, NIGERIA
[3.] Mechanical Engineering Depatment, Federal Polytechnic Offa, P.M.B. 420 Offa, NIGERIA

**Abstract**: The viability of locally sourced stones (laterite and granite) for the manufacture of concrete tiles has been investigated and analysed. The processing method employed the chemical reaction and bonding of the oxide compounds of the stones, cement and water, which after mixing and compacting produced tiles having a load capacity of 28.56 kN/mm$^2$. Analysis of the physical and mechanical properties of the specimens showed that the unfired tiles have better properties than the fired tiles. The maximum compressive strength and modulus of rupture of the unfired tiles were 45.92 Mpa and 114.3 MPa while for fired tiles the values were 36.36 MPa and 93.28 MPa respectively. Also better modulus of rupture, compressive strength and water absorption were obtained in the 20% cement tiles as compared to the 15% cement tiles. Though the unfired tiles were stronger, the fired tiles had better rate of water absorption. The fired tiles also warped twice less than the unfired tiles. The investigation achieved a 100% local sourcing and utilization of raw materials for the production of tiles which met approved standard.
**Keywords**: Laterite, Granite, Chemical bonding, Curing, Compacting, fired

## 1. INTRODUCTION

Tiles are structural or decorative items used to cover floors, roofs and walls. "It could also be extended to include small flat pieces of surfacing material that is not ceramic, such as carpet, wood, stone or cork; Ohijeagbon and Olusegun et al [1, 2]. They are slabs which vary in thickness from 5 mm to 30 mm and are square, rectangular, hexagonal, or any other shape. It provides surfaces that are durable, sanitary and easy to maintain. They are used at public buildings like mosques, churches, cinema, laboratories, hospitals and hotels. Wall tiles are a multicomponent system primarily composed of clay, carbonates, and quartz; Sousa and Holanda [3]. Typical sizes found in Nigeria are 60 x 30, 40 x 40, 30 x 30 cm and have a standard thickness of 0.6 cm. They come in different colors and are majorly ceramic, though sometimes prepared without the application of external heat,] Samuel [4] .

Tiles could be produced by various production processes such as moulding or extrusion (vertical or horizontal) processes. Concrete tiles exhibit desirable mechanical and physical properties such as rigidity and roughness. These properties therefore make them to be useable for adequate cover and load bearing situations which include drainage covers, beams and cantilevers. They are also used in places where traffic and high population is to be serviced like tiled lanes or driveways, car parks, interlocking tiles and walkways.

In recent years the clay-based ceramics have been widely used with the incorporation of industrial wastes (Dondi et-al., 1997) and (Menezes et-al., 2002). This is related to the following reasons: (i) availability of a ceramic industry which uses large amounts of raw materials; (ii) less use of natural raw materials; (iii) the main production processes are not greatly modified; and (iv) inertization of waste materials in the vitreous matrix of the fired ceramic pieces. Brazil, the fourth worldwide producer of ceramic floor and wall tile materials ITR (2006); has a production total of 556 million square meter. The total US demand for ceramic floor and wall tile reached 2.2 billion square feet in 2001 while the average annual growth between 1996 and 2001 was 9.4 percent Freedonia (2002). With consumer preferences now shifted from carpets and rugs to hard surface flooring materials, the demand for tiles which are mostly imported from Italy, Spain, Mexico or Brazil, is yet to be met. Today more than 50% of the tiles used in Nigeria are manufactured in the country. The manufacturers were faced with the problem of finding correct substitutes for the raw materials used in the tile processing; hence, the need for continued research of suitable alternative raw materials.

Previous work such as the incorporation of egg shell waste into the manufacture of red wall tiles Freire (2002), shows that the use of egg shell waste as an alternative raw material is a way of recycling the abundant egg shell waste. Also research has shown that thermal comfort of ceramic tiles increases with the introduction of porosity and crustiness Carmeane (2007). With the availability of over 90% of the raw materials needed for various categories of tiles production present in Nigeraia, the present work is to investigate the viability of some locally sourced materials such as laterite, granite and cement which were combined and compacted to make tiles. Flooring tiles made of laterite/granite/cement materials are tested to see the effects of varying granite and laterite additions on the quality of products, percentage water absorption and the mechanical properties, namely, modulus of rupture, warpage, total shrinkage and compressive strength of the tiles in conformity to internationally accepted standards.

## 2. THEORETICAL ANALYSIS

The locally sourced materials used were laterite, granite and cement. These were classified as stones and cement. The stones (literite and granite) have twelve (12) major numbers of compound elements as shown in Table 1. The percentage composition and molecular weight of the compounds are also shown in the table. Initially, when the stones, cement and water are mixed, the chemical reaction shown below occurred.

Table 1: Percentage composition and molecular weight of compounds of granite and laterite

| Compound | Granite | Laterite | Molecular Weight |
|---|---|---|---|
| $SiO_2$ | 69.9 | 72.6 | 30 |
| $Al_2O_3$ | 14.8 | 13.9 | 50 |
| $Fe_2O_3$ | 1.6 | 1.4 | 76 |
| FeO | 1.7 | 0.8 | 34 |
| MgO | 1.0 | 0.4 | 20 |
| CaO | 2.2 | 1.3 | 28 |
| $Na_2O$ | 3.3 | 3.6 | 30 |
| $K_2O$ | 4.0 | 4.0 | 46 |
| $H_2O$ | 0.8 | 1.5 | 10 |
| $TiO_2$ | 0.4 | 0.3 | 38 |
| MnO | 0.1 | 0.1 | 33 |
| $P_2O_5$ | 0.2 | 0.1 | 70 |
| | 100% | 100% | |

Source: Swanson (2006)

Cement + Water:

$$Ca_3Al_2O_6 + 6H_2O \rightarrow Ca_3Al_2(OH)_{12} \quad (1)$$

$$Ca_2SiO_4 + H_2O \rightarrow Ca_2SiO_4.H_2O \quad (2)$$

Cement + Stones (literite + granite) + Water:

$$Ca_3Al_2(OH)_{12} + Al_2Si_2O_5(OH)_4 \rightarrow Ca_3Al_4Si_2O_5(OH)_{16} \quad (3)$$

$$Ca_2SiO_4.H_2O + Al_2Si_2O_5(OH)_4 \rightarrow Ca_2Al_2Si_3O_8.(OH)_6 \quad (4)$$

$$Ca_3Al_4Si_2O_5(OH)_{16} + Fe_2O_3 \rightarrow Ca_3Al_4Si_2Fe_2O_8(OH)_{16} \quad (5)$$

$$Ca_2Al_2Si_3O_8.(OH)_6 + Fe_2O_3 \rightarrow Ca_2Al_2Si_3Fe_2O_{11}(OH)_6 \quad (6)$$

The products of Equations 3, 4, 5, and 6 in Kilogramme weight are,

$$Ca_3Al_4Si_2O_5(OH)_{16} = (20\times3)+(13\times4)+(14\times2)+(8\times5)+(9\times16) = 324\,kg \quad (7)$$

$$Ca_2Al_2Si_3O_8.(OH)_6 = (20\times2)+(13\times2)+(14\times3)+(8\times8)+(9\times6) = 226\,kg \quad (8)$$

$$Ca_3Al_4Si_2Fe_2O_8(OH)_{16} = (20\times3)+(13\times4)+(14\times2)+(26\times2)+(8\times8)+(9\times16) = 400\,kg \quad (9)$$

$$Ca_2Al_2Si_3Fe_2O_{11}(OH)_6 = (20\times2)+(13\times2)+(14\times3)+(26\times2)+(8\times11)+(9\times6) = 302\,kg \quad (10)$$

Both Eq. 9 and 10 are multiplied by a molecular factor of $\frac{100}{76}$ due to $Fe_2O_3$ being the heaviest compound of the stones (laterite and granite) in the mixture. Hence total weight as a result of the mixture by weight of 0.7: 1: 1: 3 for water, cement, granite and laterite respectively, is given as shown below

$$\textit{Total weight of product per unit area} = (324\times1.7)+(226\times1.7)+\left(302\times1\times\frac{100}{76}\right)+\left(400\times3\times\frac{100}{76}\right)kg = 2911.32 kg/mm^2$$

The load capacity P per unit of tile is,

$$P = mf = 2911.32 \text{ x } 9.81 = 28.56 \text{ KN/mm}^2 \quad (11)$$

Where m is designed mass by molecular structure of mixture, and f is acceleration due to gravity. The load capacity of 28.56 kN/mm² is more than adequate to carry all household appliances like beds, furniture, cookers, refrigerators, air conditioning units, washing machines, vehicles and human weight etc. But for highways, streets and alleys, a different compound mix structure is required. Firing the tiles had the effect of reducing strength because the chain bond between the molecules of the compound mixture was mostly broken. This type of tile is best applied without firing as it has the capacity to increase in strength with age.

## 3. MATERIALS AND METHODS

### 3.1. Equipment and Working Materials

Fundamental procedure used for production of the tiles was similar to those used by Ohijeagbon (1995). The manufactured concrete tiles were produced using a metallic vertical mould made from angle bars and having a right-angle construction. The produced tiles were pressed in the mould to a uniform thickness of 1.4 cm, and facial dimensions of 15 cm x 15 cm. The mould was simple to handle and was operated in conjunction with a mechanical press for production of the tiles.

The raw materials used were laterite (red clay), granite, Portland cement and portable water. Cement was used as a binder for all the constituent materials while granite served as a coarse aggregate and also as a stabilizer to control the strength, shrinkage and cracking effect of the tiles. Varying laterite-granite-cement mix which was investigated in relation to the physical and mechanical properties of tiles was stirred together for about 2 minutes before 14% water was added. Each batch of the damped mixture was thoroughly mixed together for about 3 minutes to eliminate lumps and to ensure homogenous mixing before moulding. Measured quantities for each tile mixture was placed in the mould box and then pressed with a punch with a compaction load of 25kN. A maximum particle size of 1000 $\mu m$ was utilised for the mixed materials. The produced experimental concrete tiles were cured for at least 10 days, without aid, in room ambient conditions, which is 25-30 degree Celsius. In order to also investigate the characteristics of produced tiles when subjected to heat, samples of the tiles were fired to a temperature not exceeding 680 $^0$C; since granite cracks at temperatures in excess of 700 $^0$C.

### 3.2. Experimental Test Procedures

**Water Absorption Test**

The mass of each specimen tested was first determined by weighing on a weighing balance and their values recorded, as the dry mass, $M_d$. Each specimen was then submerged in cold water for about 24 hours, after which the specimens were taken out of the water and their surfaces wiped with a piece of cloth to remove excess water. The new mass was determined by weighing and recorded as the saturated mass, $M_s$. The percentage water absorption Ohijeagbon (1995) was then calculated by using the relation below:

$$A = \frac{(M_s - M_d)}{M_d}\times 100\% \quad (12)$$

where, A = % water absorption

**Bulk Density Determination**

Test specimens were dried to constant mass after curing, and the dry mass, $M_d$ was determined. The bulk density, B in grams per cubic centimetre, of a specimen is the quotient of the dry mass divided by volume. The volume, V was determined from the surface dimensions, namely length, width and thickness. The bulk density Ohijeagbon (1995) was then calculated by:

$$B = \frac{M_d}{V} \tag{13}$$

**Modulus of Rupture Test**

The specimens tested were placed horizontally and centrally on two knife-edge vertical supports in an overlapping manner Folurunsho (2001). The specimens were then loaded centrally by means of an overhanging wire cord and a hanger hooked on the wire with which the specimens were loaded with known values of masses until failure occurred. The modulus of rupture for each specimen was calculated by:

$$M = \frac{8PL}{\pi T^3} \tag{14}$$

where, M is the modulus of rupture (MPa), P is load at rupture (N), L is distance between supports (mm), and T is the average thickness of the specimen tested (mm).

**Compressive (Crushing) Test**

Each test specimen was placed between the jaws of a manually operated hydraulic press machine. Load was then gradually applied on tiles via a cylindrical piece of metal of 19.5mm diameter and 30mm in length, until the first line crack was observed. The compressive strength for each specimen Ohijeagbon (1995), was calculated by:

$$C_s = \frac{P_c}{A_c} \tag{15}$$

where, $C_s$ is the compressive strength of the specimen (MPa), $P_c$ is the total load on the specimen at failure (N) and $A_c$ is the calculated area of the bearing surface on the specimen tested (mm$^2$).

**4. DISCUSSION OF RESULTS**

The compounds on Tab.1 were the stones (granite and laterite) which after mixing with Portland cement and water, chemically reacted as shown in Eq. (1) to (10) to produce the tile which had a load capacity of 28.56 kN/mm$^2$. Therefore during the compacting process care was taken to see that the compaction load did not exceed 25 kN/mm$^2$.

The modulus of rupture for 20% cement unfired tiles was higher than that of fired tiles Fig.1 and this was as a result of the setting and curing processes which resulted to natural hardness. Also, for the fired tiles the hardness increased as a result of reduction in toughness and bending moment with increase in brittleness. However, a maximum value of 93.28 MPa and 114.3 MPa was obtained for modulus of rupture in fired and unfired tiles respectively Fig.1; when equal composition of laterite and granite was used. This was due to the good adhesive forces that existed between laterite and granite particles which exceeded cohesive forces respectively within the individual particles. Similarly, the compressive strength for unfired tiles was higher in value (45.92 MPa) than that for fires tiles (36.37 MPa). This was because granite cracks badly under fire Samuel (1995), and this reduced the compressive strength. The compressive strength reached the highest value when equal composition of granite and laterite was mixed.

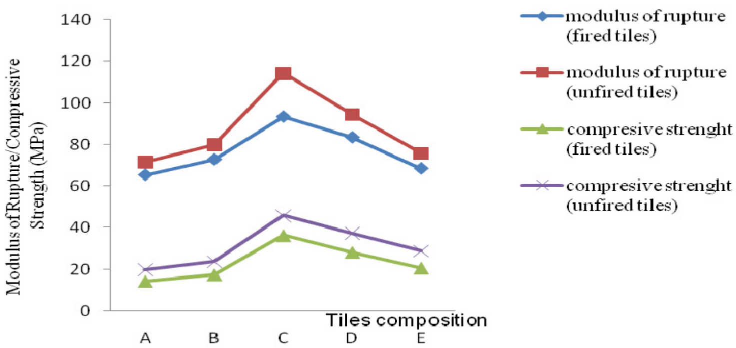


Figure 1. Mechanical properties of 20% cement tiles

1n the 15% cement tile, the modulus of rupture for unfired tiles was higher than that for fired tiles. Similar explanation holds as given earlier in the 20% cement tiles. This accounts for the similarities observed in Fig. 1 and Fig. 2. However the difference between the modulus of rupture for the fired and unfired tiles was 21.02 MPa for 20% cement tiles and 6.06 MPa for 15% cement tiles. The higher value of 21.02 MPa obtained for the 20% cement tiles was as a result of the better curing process that occurred in the tile with higher cement composition, while the lower value obtained in the 15% cement tiles was as a result of incomplete chemical reaction which affected the bonding of the oxide compounds of the particles. The compressive strength was higher in the unfired tiles with a value of 40.38 MPa as against 36.44 MPa in the fired tiles.

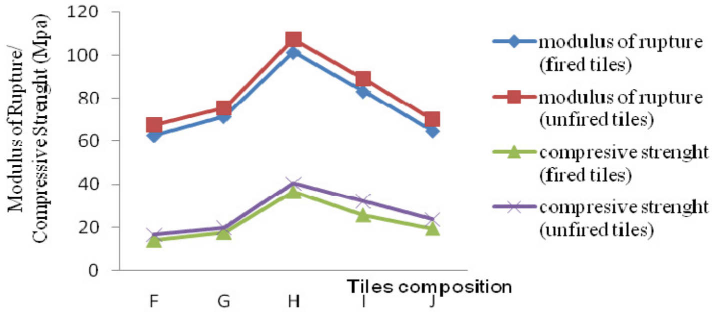


Figure 2. Mechanical properties of 15% cement tiles

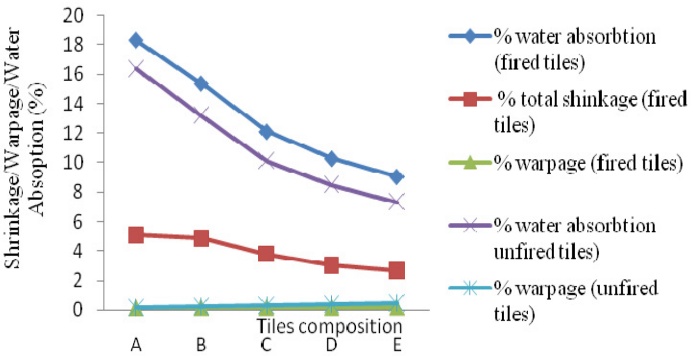


Figure 3. Physical properties of 20% cement tiles

Experimental results obtained showed that for both 20% cement tiles and 15% cement tiles, the modulus of rupture and compressive strength were higher in the unfired tiles than fired tiles (Fig. 1 and Fig. 2).

The physical properties of fired and unfired tiles with 20% cement mix (figure 3), shows that the percentage of water absorption for the fired tiles was higher than that of the unfired tiles with the highest value being 18.3% for fired and 16.39% for unfired. This was as a result of the unfired tiles, being closer to saturation point than the fired tiles, from which moisture has been extracted. Decrease in the percentage of water absorption was observed to increase with modulus of rupture and compressive strength of concrete tiles.

However the percentage water absorption decreased with increase in granite or decrease in laterite for different compositions of tiles. The percentage warpage for both fired and unfired tiles showed little or no difference with their values being less than a unity (Fig. 3) and this showed that warpage is unaffected by firing but by production processes. Also the percentage shrinkage for fired tiles in both 20% and 15% cement tiles decreased with increase in granite for different composition of tiles (Fig. 3 and Fig. 4).

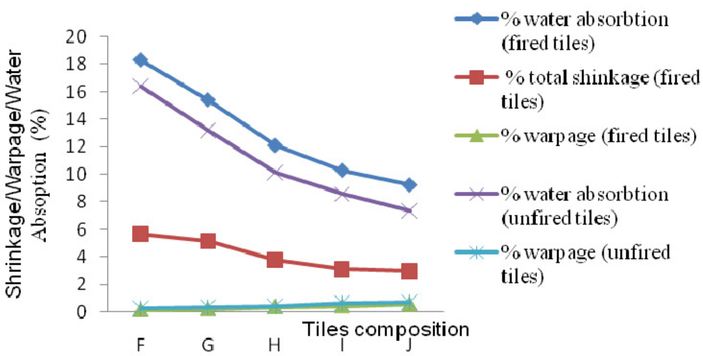


Figure 4. Physical properties of 15% cement tiles

In the 15% cement tiles, the physical properties of fired and unfired tiles were similar with that of 20% cement tiles (figure 4). But percentage warpage for 15% cement tiles had a greater value than that of 20% tiles. In general, percentage warpage increased slightly with increase in granite. This was because the cohesiveness of the particles reduced and the surface finishing was rougher as granite constituent increased

**5. CONCLUSION**

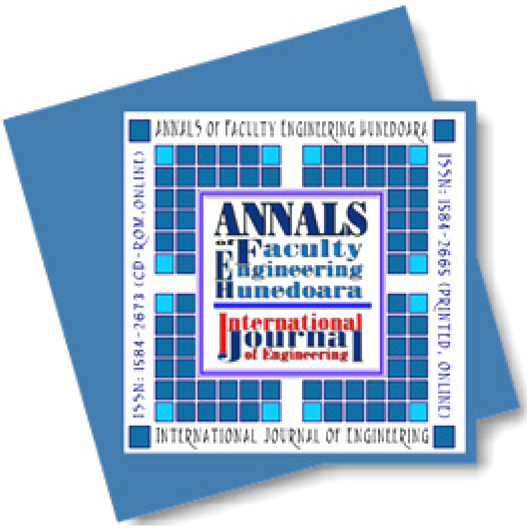
Tiles of size (15 x 15 x 1.4 cm) were made from locally sourced materials. The method which employed the chemical reaction and bonding of the oxide compounds of the stones (laterite and granite), cement and water, produced a tile which had a load capacity of 28.56 kN/mm$^2$. The unfired tile was observed to have better mechanical properties than the fired tile. The maximum compressive strength and modulus of rupture of the unfired tile were 45.92 MPa and 114.3 MPa while for fired tile the values were 36.36 MPa and 93.28 MPa respectively. The rate of water absorption was better with the fired tiles than unfired tiles and that was the relative advantage which fired tile has over unfired tiles. Also fired tiles warp over two times less than the unfired tiles, hence the type of application should decide whether fired or unfired tiles should be used. Better modulus of rupture, compressive strength and water absorption was obtained in the 20% cement tiles as compared to the 15%. Unfired tiles were stronger than fired tiles and best mechanical properties were obtained when same quantity of granite and laterite was mixed. Therefore 20% cement mix of concrete tiles and equal quantities of laterite and granite with unfired process is recommended for tiles production for optimum qualities and properties to be achieved. Finally, the analysis showed that 100% sourcing of the raw materials for manufacture of tiles is possible

**Aknowledgement**

Authors acknowledge Mr S. Raji, Mr S. Arinde and the technical Staff of the Central Workshop, University of Ilorin.

**References**

[1.] Ohijeagbon, O. I. Manufacturing of Tiles Using Cement and Clays M.Eng. (Mech.) Research Project Report, University of Ilorin, Nigeria. Pp. 1-87, 1995.
[2.] Sousa, S. J.G and Holanda, J. N, F. Ceramic Int. Vol. 31 pp. 215-222, 2005
[3.] Samuel, J. O. Manufacturing of Ceramic Tiles, Using Firing Technique M.Eng. (Mech.) Research Project Report, University of Ilorin, Ilorin, Nigeria. Pp. 40 1995.
[4.] Swanson, C. O. The Origin, Distribution and Composition of Laterite. Vol 6 No.2, 2006.
[5.] Dondi, M. M. and B. Fabbri. Tile and Brick Intl. Vol. 13, pp. 28-225, 1997.
[6.] Menezes, R. R. Neves, G. A and H. C. Ferreira. Rev. Bra. Eng. Agr.e Amb. Vol. 6 No. 2, 2002 .
[7.] Information on Technical Report, World Production and Markets of Ceramic Tiles Ind. Ceram. Vol. 26 No. 1 pp. 66-67, 2006.
[8.] 8. Freedonia Focus on Ceramic Tiles, 2002 Market Report by the Freedonia Group Inc. [online] pp2,4. Accessed 10th April 2009, Available from world wide web: http// www.freedoniagroup.com
[9.] Freire M. N and J.N.F Holanda. Processing of Egg Shell Waste Bearing Wall Tiles, Sixth International Latin – American Conference on Powder Technology. Pp. 1-5, 2002.
[10.] Carmeane, E. Evaluation of the thermal comfort of ceramic floor tiles Journal of Center for Technology in Material Science, Sc/Brazil Vol. 10 No. 3 pp2, 2007.
[11.] Folorunsho, S. Concrete tiles Manufacturing and properties Studies B.Eng (Mech) Project Report University of Ilorin, Ilorin, Nigeria. pp 40, 2001.




ANNALS of Faculty Engineering Hunedoara
– International Journal of Engineering